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COMPARATIVE EVALUATION OF COKING PROPERTIES OF FOUR COALS

By Staff, Division of Bituminous Coal

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
(1961)

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COMPARATIVE EVALUATION OF COKING PROPERTIES OF FOUR COALS[1/]

by

Staff, Division of Bituminous Coal

SUMMARY

Comparative tests of four coals used industrially for coke production have been made by three laboratories of the Federal Bureau of Mines, each using its standard equipment and procedures for evaluating coal for coking. Two of the coals were blends used in the western and eastern sections of the United States, the third was a strongly coking coal widely used for producing coke in Alabama, and the fourth was a blend typical of those used for producing foundry coke in the Birmingham district. The coals used and the cokes produced from them covered a wide range of chemical and physical properties. The tests used at all three laboratories for determining the physical properties of the cokes were made according to ASTM (American Society for Testing Materials) methods. The excellent agreement found for the physical properties of the cokes indicated that, for the coals tested, the BM-AGA (Bureau of Mines-American Gas Association) 18-inch circular retort used at Pittsburgh, Pa., the 14-inch slot-type oven used at Denver, Colo., and the 17-inch slot-type oven used at Tuscaloosa, Ala., were substantially equivalent for evaluating coals for production of coke. Thus, added value is given to data obtained previously and independently at these three Bureau laboratories.

INTRODUCTION

Laboratory equipment to produce coke for evaluation has not been standardized by the industry. The results obtained with any one design of equipment have been regarded as showing only the relative values of coal to produce coke of the requisite quality. Few systematic studies have been made to correlate results obtained in different types of equipment. Results of one, in which the Bureau of Mines participated, were published recently.[2/] This

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1/ Work on manuscript completed July 1960.

2/ Swartzman, E., Botham, J. C., Tibbetts, T. E., Burrough, E. J., and Birge, G. W., A Study of the Relation between the Properties of Cokes Produced by Means of Two Laboratory Methods and Coke Produced Industrially: Mines Branch Investigation Report IR 58-138, Canada Dept. Mines and Tech. Surveys, 1958, 68 pp.

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report summarizes another and gives data obtained from carbonizing four coals tested simultaneously in three Bureau laboratories at Pittsburgh, Pa., Denver, Colo., and Tuscaloosa, Ala., with different designs of equipment and different operating schedules.

The selection of carbonization techniques used at the three laboratories was dictated by historical and local considerations. At Pittsburgh, the Bureau began the first comprehensive study of the carbonization properties of coals. The purpose of this study was basically to survey as many coals as could conveniently and practically be studied by a consistent technique, in order to provide a basis for comparing these coals. This was a generalized study, not keyed to any geographical area, as it was initiated at a time when the Pittsburgh station served as the only coal testing laboratory of the Bureau of Mines. The 13-inch and 18-inch circular ovens served this purpose and produced sufficient coke for physical testing.

The Denver and Tuscaloosa laboratories, however, were faced with the problem of studying local coals and carbonization problems as applied to local practice. Each laboratory selected an oven design comparable to the industrial ovens used in their area. In the Denver area, both 18-inch and 14-inch ovens are used commercially, but the major problems being studied at the time the Denver oven was being built concerned the carbonization of weakly coking coals, particularly those from western Colorado and Utah. For such coals, the Bureau used the narrower oven, because it is not practical to attempt to coke through the charge of such coals in an oven wider than 14 inches. The 17-inch oven used in Tuscaloosa is representative of the commercial slot-ovens used in the southern and eastern States and has a movable wall permitting measurement of the pressure developed during carbonization.

The BM-AGA method for determining the carbonizing properties of coal has been used by the Bureau at Pittsburgh since 1929 when a survey of gas-, coke-, and byproduct-making properties of American coals was begun in cooperation with the American Gas Association. Since that time more than 800 coals have been studied by this method. Originally, the survey concerned the effect of temperature of carbonization from 500° to 1,100° C.(932° to 2,012° F.) on the yields and qualities of the products obtained from a charge of coal in a circular retort 13 inches in diameter and 26 inches in height. The objective in recent years has been principally to determine yields of products and quality of coke by standard ASTM methods from carbonizing coal at 900° C. (1,652° F.) in an 18-inch retort. The 13-inch retort is used when the coal available is insufficient for the larger retort and for carbonization tests at lower temperatures. For all four coals tested in this investigation, both the 13-inch retort, containing a charge of about 90 pounds, and the 18-inch retort, containing a charge of about 180 pounds, were used at 900° C.(1,652° F.). One of the coals also was carbonized at 800° C.(1,472° F.). A description of the apparatus used and of the procedures followed in obtaining the data reported is given in appendix I.

At the Bureau's Denver laboratory, carbonization tests were made in a 10-inch diameter, circular retort, holding 50 pounds of coal, at

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900° C.(1,652° F.) using a modified BM-AGA technique (See appendix II). In addition, tests were made in a 14-inch-wide, slot-type oven, holding 500 pounds of coal, with the flue temperatures maintained at an average temperature of 2,280° F.(1,249° C.) (See appendix III).

A larger scale experimental slot-type oven was used in the studies performed at the Tuscaloosa laboratory. The oven has a width of 17 inches and holds a charge of about 850 pounds of coal. A description of the oven and of its operation is given in appendix IV. A flue temperature of 2,400° F. (1,316° C.) was used for all four coals, and for one coal 2,000° F. (1,093° C.) was used.

Although conditions of carbonization differed in the three laboratories, by joint agreement all tests were made under conditions considered standard for the laboratory concerned. Results thus obtained should contribute to a knowledge of the significance of such differences in conditions in predicting the coking characteristics of coals.

In the original plan, one coal from each district, typical of those used commercially in the area, was to be tested simultaneously at each of the three laboratories to minimize possible effects of time elapsed between collection and testing of the samples. The three coals chosen represented raw materials used industrially for production of blast furnace coke. On completion of the tests on these three coals, another sample representing a foundry blend was selected, as the coke produced for foundry use differs in many respects from furnace coke. A description of the methods of collecting the samples and their analyses are given in this report.

Methods of characterizing the coke produced at each laboratory have common factors. Results of these tests and also of tests that have received local acceptance as to significance are included in the tables.

COLLECTION AND ANALYSES OF SAMPLES

The four coals used in this study were (1) a sample of the blend used in a western plant, (2) a southern strongly coking coal, (3) a blend from an eastern plant, and (4) a foundry blend, typical of those used in the Birmingham district.

(1) Western plant blend: The nominal blend consists of 1 by 0-inch material composed of 85 percent of Sunnyside (Utah) high-volatile coal and 15 percent of two low-volatile and one medium-volatile Oklahoma coals in approximately equal proportions. The test lot collected for this study was a composite of 20 belt samples taken over a 4-day sampling period. These samples were placed in sealed drums and were shipped to Denver, where the total of 14,600 pounds was long-piled and distributed over 72 drums. Each drum contained 20 10-pound increments. Drums were selected at random to provide sufficient coal for the tests at each laboratory; the coal was crushed to 1/4 by 0-inch size (round hole screen) in a hammermill and was shipped or stored in sealed drums. The coal was 95 percent minus one-eighth inch, and 12.5 percent passed through a 100-mesh screen.

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(2) Southern coal: Run-of-mine coal from the Bessie Mine (Alabama) was crushed to approximately 1-1/2-inch top size in a breaker, and the underflow was cleaned using heavy media, tables, supersorter, and flotation units. The product contained some oil, since the flotation circuit at the washer treated approximately 20 percent of the raw coal and used about 16 pounds of kerosene per ton of feed to improve drainage characteristics. Except for a low-ash product removed from certain of the tables for specialty uses and amounting to about 10 percent of the combined washed coal from all units, the washed coal from the different units was combined and stored in a washed-coal bin for shipment to the coke works. A sample, amounting to approximately 9 tons, was taken directly from this bin in a single lot, was transported to Tuscaloosa, was crushed to approximately one-fourth inch with a hammermill, and was mixed by alternately long-piling and coning the entire sample twice. The coal was 90 percent minus one-eighth inch, and 11 percent passed through a 100-mesh screen. The lot was then stored in sealed bins containing 1/2 to 1 ton each. Approximately 3 tons of material, representing the entire contents of five bins, were removed and again mixed by alternately long-piling and coning. This material was shoveled from the base of the cone into 16 drums placed equidistantly about the cone. Four drums were selected at random for shipment to Denver and three for sending to Pittsburgh. The remaining nine drums were retained for carbonizing tests at Tuscaloosa.

(3) Eastern plant blend: The head sample consisted of a 2-ton lot composed of 30-percent medium-volatile Pocahontas No. 4 coal and of 70-percent high-volatile A Pittsburgh coal collected by plant personnel. The coal was 55 percent minus one-eighth inch, and 8 percent passed through a 100-mesh screen, while 32 percent was larger than one-fourth inch. The sample was received at the Pittsburgh laboratory in burlap bags, each containing about 100 pounds of coal. The entire sample was formed into a long pile and was divided by shoveling approximately 10-pound increments alternately into 55-gallon drums. Three of the sealed drums were shipped to Tuscaloosa and three to Denver. The portion retained at Pittsburgh was further divided into 100-, 200-, and 500-pound samples for BM-AGA 13- and 18-inch retort tests and a sole-oven expansion test. Approximately 20 pounds of coal were obtained for chemical and size analyses.

(4) Foundry blend: The blend was composed of 15 percent high-volatile coal from the Black Creek bed (Alabama), 43 percent medium-volatile coal from the Blue Creek bed (Alabama), 35 percent low-volatile Pocahontas No. 3 bed coal, and 7 percent Pennsylvania anthracite. The components were obtained at a single local coke plant and represented the material being used to produce commercial foundry coke at the time of sampling. The anthracite was No. 5 buckwheat and was used without crushing; each of the other components was crushed to approximately minus one-fourth inch with a hammermill and was mixed by coning. The blend was prepared by using a cement mixer. Two hundred pounds, consisting of weighted quantities of the four components, were charged to the mixer along with No. 5 fuel oil in the amount of one-half gallon per ton. The mixer was operated for 10 minutes, and, except for a small increment withdrawn for moisture determination, the total contents were emptied into a 55-gallon drum, each drum containing exactly two mixer charges. Two drums

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were selected at random and were shipped to Pittsburgh; three drums were shipped to Denver. To obtain the necessary quantity of material for testing, the contents of two or three drums were mixed by coning twice, and the required weight of sample was taken by shoveling from the base of the cone. Over 95 percent of the blend was minus one-eighth inch, and 12 percent passed a 100-mesh screen.

Chemical Analyses of Coals

Chemical analyses of the coals on the as-received and moisture- and ash-free basis are given in table 1. Samples for these analyses were collected from the head sample at the time the coals were divided for distribution to the separate laboratories. In addition, proximate analyses were made of the individual samples at each laboratory before carbonization. The latter analyses agreed well with those of the head samples, indicating that sampling techniques were satisfactory.

TABLE 1. - Chemical analyses of coals

	Western plant blend	Southern coal	Eastern plant blend	Foundry blend
Proximate analysis, as received:				
Moisture.....percent..	5.8	6.1	2.7	4.4
Volatile matter.....do.....	35.6	24.9	33.1	23.3
Fixed carbon.....do.....	52.2	58.7	57.4	66.3
Ash.....do.....	6.4	10.3	6.8	6.0
Proximate analysis, m.a.f.[1]:				
Volatile matter.....percent..	40.5	30.1	36.5	26.0
Fixed carbon.....do.....	59.5	69.9	63.5	74.0
Ultimate analysis, m.a.f.:				
Hydrogen.....percent..	5.6	5.3	5.4	4.8
Carbon.....do.....	83.6	87.2	86.4	88.8
Nitrogen.....do.....	1.8	1.9	1.6	1.7
Sulfur.....do.....	1.3	0.9	1.5	0.9
Oxygen (by difference).....do.....	7.7	4.7	5.1	3.8
British thermal units per pound, m.a.f...	14,880	15,450	15,390	15,400

1/ Moisture and ash free.

The moisture- and ash-free volatile matter of the four coals ranged from 26.0 percent for the foundry blend to 40.5 percent for the western plant blend. Three of the coals contained from 6.0 to 6.8 percent ash; the southern plant blend contained 10.3 percent ash. The sulfur content of the coals ranged from 0.9 to 1.5 percent.

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Plastic Properties of Coals

Table 2 gives the free-swelling indexes, agglutinating values, Gieseler plastometer, and Audibert-Arnu dilatometer data, and expansion as determined in the sole-heated oven for the coals. The results of these tests, which have received local acceptance for evaluating coking properties of coals, indicate the wide range of values for charges to industrial ovens. The agglutinating values and free-swelling indexes ranged from 5.3 to 8.9 and 4-1/2 to 8, respectively. The maximum fluidity, as determined in the Gieseler plastometer, ranged from 16 to 9,300 dial divisions per minute. The maximum dilatation as determined in the Audibert-Arnu dilatometer, which has been proposed by the International Standards Organization as a specification for coking coals, ranged from 6 to 210 percent. Of the four coals, the eastern plant blend contracted the most in the sole-heated oven test--more than 10 percent--and the southern coal contracted the least. In fact, the average of the two values given for the latter coal in table 2 would indicate neither expansion nor contraction.

CARBONIZATION DATA AND COKE PROPERTIES

The data describing the carbonization conditions at the three laboratories for these tests are given in tables 3 to 6 inclusive. These same tables include the data on the properties of the cokes produced.

DISCUSSION

For many years, a general opinion has been held that only a full-scale coke-oven test is acceptable as a criterion of the quality of the coke produced from a given coal charge. Studies by each of the three Bureau laboratories collaborating in this investigation have shown correlation between laboratory evaluation of coals for high-temperature carbonization and commercial practice.[3 4 5 6] While the equipment, procedures, and operating conditions have been standardized at each laboratory, the differences might have contributed to significant differences in the properties of the cokes produced. The principal differences in this study were in the retort systems--circular retorts ranging from 10 to 18 inches in diameter and slot-type ovens ranging from 14 to 17 inches--and in operating conditions, that is, carbonizing temperatures and times, charging techniques, and handling of coke before

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3/ Walters, J. G., and Birge, G. W., Duplicability Studies of the BM-AGA Test Method and Correlation with Industrial Coking: Bureau of Mines Rept. of Investigations 5467, 16 pp.

4/ Denver laboratory, unpublished.

5/ Gayle, J. B., and Auvil, H., Development of New Experimental Coke Oven: Bureau of Mines Rept. of Investigations 4923, 1952, 17 pp.

6/ Gayle, J. B., and Gulledge, E. L., Carbonizing Procedures with New Experimental Coke Oven: Bureau of Mines Rept. of Investigations 5011, 1954, 12 pp.

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testing. Since each laboratory uses ASTM standard test procedures for measuring coke properties, any difference found in these properties should not be attributed to test procedures but to differences in equipment and operating conditions.

TABLE 2. - Plastic properties of coals

	Western plant blend	Southern coal	Eastern plant blend	Foundry blend
Free swelling index	4-1/2	8	8	7-1/2
Agglutinating value	5.3	8.0	8.9	6.1
Gieseler plastometer data:				
Initial softening temperature, °C.	370	377	347	383
Fusion temperature, °C.	424	422	404	428
Temperature of maximum fluidity, °C.	437	460	438	458
Solidification temperature, °C.	463	499	485	495
Maximum fluidity, ddpm	16	4100	9300	273
Audibert-Arnu dilatometer data:				
Contraction, percent	35	31	30	28
Dilatation, do	6	200	210	30
Softening temperature, °C.	353	361	356	382
Temperature of maximum contraction, °C.	411	410	400	430
Temperature of maximum dilatation, °C.	437	467	467	471
Expansion (+) or contraction (-), percent:				
End (1)[2], Pittsburgh	-5.8	+2.8	-12.2	
End (2)[2], Tuscaloosa	-6.5	-1.5	-13.2	-2.2

1/ ddpm = dial divisions per minute.

2/ Determined in sole-heated oven[3 4 5]; observed values corrected to a standard condition of 55 lb./cu. ft., 1 percent moisture.

3/ Auvil, H. S., and Davis, J. D., Determination of the Swelling Properties of Coal during the Coking Process: Bureau of Mines Rept. of Investigations 3403, 1938, 18 pp.

4/ Auvil, H. S., Davis, J. D., and McCartney, J. T., Expansion of Coal during Coking: Bureau of Mines Rept. of Investigations 3451, 1939, 21 pp.

5/ McCartney, J. T., and Davis, J. D., Expansion of Coal during Coking: Bureau of Mines Rept. of Investigations 3644, 1942, 23 pp.

The coals selected for this investigation are used industrially in the western, southern, and eastern sections of the United States. They were collected at commercial plants and subdivided into samples by the Bureau personnel of the three laboratories. The samples were distributed to each laboratory for simultaneous testing to avoid possible effects of time

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elapsed between sampling and carbonization. Proximate analyses of individual samples made at each laboratory before carbonization agreed well with those of the head samples and showed adequate sampling and preparation techniques. The physical and chemical properties of the coals covered a wide range. The coal charges differed in size consist from 55 to over 95 percent through one-eighth inch and from 8 to 12 percent through a 100-mesh screen. The moisture- and ash-free volatile matter ranged from 26 to 40.5 percent. Free-swelling and agglutinating values ranged from 4-1/2 to 8 and from 5.3 to 8.9, respectively. The Gieseler maximum fluidity and the Audibert-Arnu maximum dilatation of the charges ranged from 16 to 9,300 and from 6 to 210, respectively.

The properties of the cokes produced from the four coals also covered a wide range. Cokes produced in the standard equipment and under the standard operating conditions of the three laboratories, excluding the lower-temperature carbonization of the foundry blend, had an average 1-1/2-inch ASTM shatter index that ranged from 73.0 to 93.7, a 1-inch ASTM tumbler index that ranged from 36.3 to 52.7, a 1/4-inch ASTM tumbler index that ranged from 55.0 to 70.0, and an apparent specific gravity that ranged from 0.79 to 0.94. Excluding the Pittsburgh laboratory, which does not determine size distribution of the coke, the average coke size ranged from 2 to 3 inches. ASTM strength indexes could not be determined for coke produced in the 10-inch modified BM-AGA retort at Denver because of insufficient material. Those from the 13-inch BM-AGA retort at Pittsburgh differed slightly but consistently from those for coke from the 18-inch retort. The coke from the foundry blend that was produced in the Tuscaloosa oven at lower than standard temperatures was larger in size and had a lower 1/4-inch ASTM tumbler index than that from either the Tuscaloosa oven or the BM-AGA retort under standard conditions.

The size distribution and the average size of the cokes produced under the standard conditions in the Denver 14-inch slot-type oven and the Tuscaloosa 17-inch slot-type oven were substantially the same. For the cokes produced under the standard conditions at all three laboratories, the physical properties of the cokes from all four coals, including shatter and tumbler indexes and apparent specific gravity, were in excellent agreement. Because of the considerable differences in the standard methods of carbonization at these laboratories, this result could not be anticipated; rather, one might have expected small but consistent differences in coke properties. Even acknowledging the limited scope of the present study, the value of the many studies published by the Bureau from the three laboratories in evaluating coal for coke production is enhanced in that it indicates that data are directly comparable for measurements common to all. The doubtful value of data on cokes produced in circular retorts as contrasted to slot-type ovens also is removed, increasing the significance of the data obtained on more than 800 coals in the BM-AGA survey.

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TABLE 3. - Western plant blend: Carbonization data and coke properties

	Pittsburgh[1]		Denver[2]		Tuscaloosa[3]
Type of carbonization equipment	Circular retort	Circular retort	Circular retort	Slot-type oven	Slot-type oven
Diameter or width, inches	18	13	10	14	17
Carbonizing conditions:					
Temperature					
Average flue	--	--	--	2,280° F.	2,400° F.
Average wall	900° C.	900° C.	900° C.	1,895° F.	2,180° F.[4]
Final coke	--	--	--	--	2,140° F.
Coking time:					
Gross, hours	12.2[1]	7.5[1]	--	15.5[2]	18.0
Net, do	--	--	--	13.0[2]	--
"True", do	--	--	--	--	13.7[3]
Moisture, as carbonized, percent	5.8	5.8	--	6.6	6.2
Bulk density, as carbonized, lb./cu.ft.	50.7	51.0	50.0	50.6	48.8
Coke yield, as carbonized, percent	64.7	64.2	64.5	63.1	63.8
Tar yield, as carbonized, do	6.4	6.4	--	--	--
Gas yield, as carbonized, do	16.5	17.0	--	--	--
Cumulative screen analysis of coke:					
On 6.0-inch, do	--	--	--	--	--
On 5.0-inch, do	--	--	--	--	--
On 4.0-inch, do	--	--	--	1.5	1.3
On 3.0-inch, do	--	--	6.0	10.8	8.2
On 2.0-inch, do	--	--	28.7	47.1	51.7
On 1.5-inch, do	--	--	60.8	79.9	83.4
On 1.0-inch, do	--	--	91.9	92.6	93.2[4]
On 0.75-inch, do	--	--	--	--	95.2
On 0.50-inch, do	--	--	97.7	95.5	--
On 0.25-inch, do	--	--	98.3	96.6	--
Average size:					
Entire sample, inches	--	--	1.781	2.063	2.094
Plus 1-inch, do	--	--	1.880	2.196	2.215
Coke strength indices:					
Drop shatter, ASTM:					
On 2.0-inch, percent	--	--	--	39	42
On 1.5-inch, do	74	62	--	74	71
On 0.5-inch, do	--	--	--	97	96
Tumbler, ASTM:					
On 1.0-inch, do	40	36	--	38	31
On 0.25-inch, do	69	69	--	71	70
Specific gravity of coke:					
Apparent	0.76	0.75	0.73	0.80	0.80
True	1.92	1.93	1.90	1.86	1.87
Cell space, percent	60	61	62	57	57
Chemical analysis of coke:					
Proximate, dry basis:					
Volatile matter, do	1.4	--	1.7	1.4	1.2
Fixed carbon, do	88.2	--	87.9	88.3	88.3
Ash, do	10.4	--	10.4	10.3	10.5
Ultimate, m.a.f.:					
Hydrogen, do	--	--	--	0.3	--
Carbon, do	--	--	--	97.0	--
Nitrogen, do	--	--	--	1.1	--
Sulfur, do	1.1	--	1.1	1.1	1.1
Oxygen (by difference), do	--	--	--	0.5	--
British thermal units, m.a.f	--	--	14,420	14,170	--

1/ See appendix I.
2/ See appendix II and III.
3/ See appendix IV.
4/ Estimated.

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TABLE 4. - Southern coal: Carbonization data and coke properties

	Pittsburgh[1]		Denver[2]		Tuscaloosa[3]
Type of carbonization equipment	Circular retort	Circular retort	Circular retort	Slot-type oven	Slot-type oven
Diameter or width, inches	18	13	10	14	17
Carbonizing conditions:					
Temperature:					
Average flue	--	--	--	2,280° F.	2,400° F.
Average wall	900° C.	900° C.	900° C.	1,930° F.	2,180° F.
Final coke	--	--	--	2,100° F.	2,140° F.
Coking time:					
Gross, hours	11.7[1]	7.2[1]	--	15.5[2]	16.6[2]
Net, do	--	--	--	12.1[2]	--
"True", do	--	--	--	--	12.6[3]
Moisture, as carbonized, percent	5.8	5.8	7.0	7.0	6.0
Bulk density, as carbonized, lb./cu.ft.	50.7	50.6	50.0	50.4	50.7
Coke yield, as carbonized, percent	73.6	73.2	72.8	71.7	74.4
Tar yield, as carbonized, do	4.9	4.8	--	--	--
Gas yield, as carbonized, do	12.3	12.6	--	--	--
Cumulative screen analysis of coke:					
On 6.0-inch, do	--	--	--	--	--
On 5.0-inch, do	--	--	--	1.5	0.0
On 4.0-inch, do	--	--	--	5.4	5.1
On 3.0-inch, do	--	--	21.7	32.4	34.6
On 2.0-inch, do	--	--	64.2	82.6	79.7
On 1.5-inch, do	--	--	89.3	94.4	92.0
On 1.0-inch, do	--	--	96.7	96.3	96.6[4]
On 0.75-inch, do	--	--	--	--	97.4
On 0.50-inch, do	--	--	98.4	97.7	--
On 0.25-inch, do	--	--	98.6	98.1	--
Average size:					
Entire sample, inches	--	--	2.368	2.699	2.676
Plus 1-inch, do	--	--	2.434	2.791	2.756
Coke strength indices:					
Drop shatter, ASTM:					
On 2.0-inch, percent	--	--	--	75	77
On 1.5-inch, do	90	87	--	93	91
On 0.5-inch, do	--	--	--	99	98
Tumbler, ASTM:					
On 1.0-inch, do	51	49	--	53	54
On 0.25-inch, do	58	60	--	59	63
Specific gravity of coke:					
Apparent	0.86	0.86	0.82	0.90	0.91
True	1.94	1.94	1.92	2.03	2.03
Cell space, percent	56	56	57	56	55
Chemical analysis of coke:					
Proximate, dry basis:					
Volatile matter, do	1.4	1.2	1.7	1.6	1.1
Fixed carbon, do	84.7	84.7	84.2	84.7	84.7
Ash, do	13.9	14.1	14.1	13.7	14.2
Ultimate, m.a.f.:					
Hydrogen, do	--	--	--	0.2	--
Carbon, do	--	--	--	97.2	--
Nitrogen, do	--	--	--	1.1	--
Sulfur, do	0.8	0.8	0.8	0.8	0.8
Oxygen (by difference), do	--	--	--	0.7	--
British thermal units per pound	--	--	14,440	14,150	--

1/ See appendix I.
2/ See appendix II and III.
3/ See appendix IV.
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TABLE 5. - Eastern plant blend: Carbonization data and coke properties

Type of carbonization equipment	Pittsburgh[1]		Denver[2]		Tuscaloosa[3]
	Circular retort	Circular retort	Circular retort	Slot-type oven	Slot-type oven
Diameter or width, inches	18	13	10	14	17
Carbonizing conditions:					
Temperature:					
Average flue	--	--	--	2,280° F.	2,400° F.
Average wall	900° C.	900° C.	900° C.	--	2,180° F.
Final coke	--	--	--	2,075° F.	2,140° F.
Coking time:					
Gross, hours	11.7[1]	7.6[1]	--	15.0[2]	17.2[3]
Net, do	--	--	--	13.7[2]	--
"True", do	--	--	--	--	13.3[3]
Moisture, as carbonized, percent	2.7	2.7	--	3.0	2.7
Bulk density, as carbonized, lb./cu.ft.	53.5	56.0	50.0	56.1	54.3
Coke yield, as carbonized, percent	70.2	69.9	69.8	71.0	69.4
Tar yield, as carbonized, do	6.8	7.3	--	--	--
Gas yield, as carbonized, do	14.7	14.7	--	--	--
Cumulative screen analysis of coke:					
On 6.0-inch, do	--	--	--	--	--
On 5.0-inch, do	--	--	--	--	--
On 4.0-inch, do	--	--	--	1.2	0.9
On 3.0-inch, do	--	--	7.6	15.1	17.4
On 2.0-inch, do	--	--	45.6	63.4	63.4
On 1.5-inch, do	--	--	79.1	87.8	85.1
On 1.0-inch, do	--	--	95.6	94.4	94.3[4]
On 0.75-inch, do	--	--	--	--	96.4
On 0.50-inch, do	--	--	97.8	96.8	--
On 0.25-inch, do	--	--	98.3	97.7	--
Average size:					
Entire sample, inches	--	--	2.029	2.282	2.289
Plus 1-inch, do	--	--	2.101	2.390	2.399
Coke strength indices:					
Drop shatter, ASTM:					
On 2.0-inch, percent	--	--	--	51	57
On 1.5-inch, do	80	75	--	83	82
On 0.5-inch, do	--	--	--	99	97
Tumbler, ASTM:					
On 1.0-inch, percent	45	40	--	49	45
On 0.25-inch, do	61	65	--	66	66
Specific gravity of coke:					
Apparent	0.91	0.91	0.79	0.94	0.96
True	1.93	1.92	1.93	1.96	1.96
Cell space, percent	53	53	59	52	51
Chemical analysis of coke:					
Proximate, dry basis:					
Volatile matter, do	1.6	1.3	2.1	1.1	0.8
Fixed carbon, do	88.4	88.7	--	89.0	89.5
Ash, do	10.0	10.0	--	9.9	9.7
Ultimate, m.a.f.:					
Hydrogen, do	--	--	--	0.3	--
Carbon, do	--	--	--	97.4	--
Nitrogen, do	--	--	--	1.0	--
Sulfur, do	1.3	1.3	--	1.3	1.3
Oxygen (by difference), do	--	--	--	0.0	--
British thermal units per pound	--	--	--	14,300	--

1/ See appendix I.
2/ See appendix II and III.
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TABLE 6. - Foundry blend: Carbonization data and coke properties

Type of carbonization equipment	Pittsburgh[1]				Denver[2]		Tuscaloosa[3]	
	Circular retort	Circular retort	Circular retort	Circular retort	Circular retort	Slot-type oven	Slot-type oven	Slot-type oven
Diameter or width, inches	18	18	13	13	10	14	17	17
Carbonizing conditions:								
Temperature:								
Average flue	--	--	--	--	--	2,280° F.	2,000° F.	2,400° F.
Average wall	800° C.	900° C.	800° C.	900° C.	900° C.	1,950° F.	1,980° F.[4]	2,180° F.[4]
Final coke	--	--	--	--	--	2,110° F.	1,840° F.	2,140° F.
Coking time:								
Gross, hours	17.8	12.1	10.5	7.4	--	14.9[2]	24.0[3]	16.7[3]
Net, do	--	--	--	--	--	11.9[2]	--	--
"True", do	--	--	--	--	--	--	18.2[3]	12.1[3]
Moisture, as carbonized, percent	4.4	4.4	4.4	4.4	--	5.0	5.1	5.1
Bulk density, as carbonized, lb./cu.ft.	50.4	50.7	49.9	50.2	--	49.6	48.7	48.9
Coke yield, as carbonized, percent	76.7	76.3	76.2	76.5	75.5	74.2	--	--
Tar yield, as carbonized, do	3.5	3.3	3.8	3.5	--	--	--	--
Gas yield, as carbonized, do	10.9	11.3	10.7	11.4	--	--	--	--
Cumulative screen analysis of coke:								
On 6.0-inch, do	--	--	--	--	--	1.1	7.3	--
On 5.0-inch, do	--	--	--	--	--	4.5	28.2	0.9
On 4.0-inch, do	--	--	--	--	12.5	23.9	55.2	17.5
On 3.0-inch, do	--	--	--	--	31.3	65.0	83.4	56.3
On 2.0-inch, do	--	--	--	--	76.0	91.8	93.9	86.7
On 1.5-inch, do	--	--	--	--	91.9	95.1	96.0	93.3
On 1.0-inch, do	--	--	--	--	97.2	96.7	97.2[4]	96.2[4]
On 0.75-inch, do	--	--	--	--	--	--	97.5	97.0
On 0.50-inch, do	--	--	--	--	98.4	97.4	--	--
On 0.25-inch, do	--	--	--	--	98.9	98.1	--	--
Average size:								
Entire sample, inches	--	--	--	--	2.694	3.328	4.152	3.082
Plus 1-inch, do	--	--	--	--	2.759	3.430	4.260	3.187
Coke strength indices:								
Drop shatter, ASTM:								
On 2.0-inch, percent	--	--	--	--	--	90	94	82
On 1.5-inch, do	95	93	96	91	--	96	96	92
On 0.5-inch, do	--	--	--	--	--	99	99	98
Tumbler, ASTM:								
On 1.0-inch, do	49	50	50	49	--	48	49	48
On 0.25-inch, do	50	55	51	56	--	54	51	56
Specific gravity of coke:								
Apparent	0.86	0.88	0.84	0.87	0.81	0.87	0.91	0.91
True	--	--	--	--	1.87	1.95	1.98	1.99
Cell space, percent	--	--	--	--	57	55	54	54
Chemical analysis of coke:								
Proximate, dry basis:								
Volatile matter, do	--	--	--	--	1.5	0.8	0.7	0.8
Fixed carbon, do	--	--	--	--	90.4	90.8	91.1	91.1
Ash, do	--	--	--	--	8.1	8.4	8.2	8.1
Ultimate, m.a.f.:								
Hydrogen	--	--	--	--	0.9	0.3	--	--
Carbon	--	--	--	--	96.0	97.5	--	--
Nitrogen	--	--	--	--	1.1	0.8	--	--
Sulfur	--	--	--	--	0.8	0.8	0.8	0.7
Oxygen (by difference)	--	--	--	--	1.2	0.6	--	--
British thermal units per pound	--	--	--	--	14,490	14,190	--	--

1/ See appendix I.
2/ See appendix II and III.
3/ See appendix IV.
4/ Estimated.

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APPENDIX I

BM-AGA Carbonizing Apparatus

The Bureau of Mines-American Gas Association (BM-AGA) carbonizing apparatus, shown schematically in figures 1 and 2, consists essentially of an electric furnace, cylindrical steel retort, condensing and scrubbing train for recovery of products, and gas metering and sampling devices.

As shown in figure 2, the electric furnace (1) is 26 inches in internal diameter and 48 inches deep. A cast refractory block 18 inches in diameter and 11-1/2 inches high is located at the bottom-center of the furnace to support the retort. The furnace is heated electrically by nickel-chromium resistors evenly spaced in the furnace wall. The retort (2) is constructed of 16-gage mild steel in the wall and 10-gage steel in the top and bottom. It is 26 inches high and normally is either 13 or 18 inches in diameter. The effluent gases and vapors pass from the retort through a 2-inch-diameter pipe, located at the top-center, and enter an air-cooled tar trap (3), where the heavier tars are collected. The gas and vapors then pass through a water-cooled tubular condenser (4), where they are cooled to room temperature, and the liquor, together with additional tar, is collected. The last traces of tar mist are removed by one of the alternate electrostatic precipitators (5 and 6). The gas then passes successively through the packed scrubbers (7), where the ammonia is removed with sulfuric acid and (8 and 9) for removal of hydrogen sulfide and carbon dioxide with caustic soda. Next, the gas

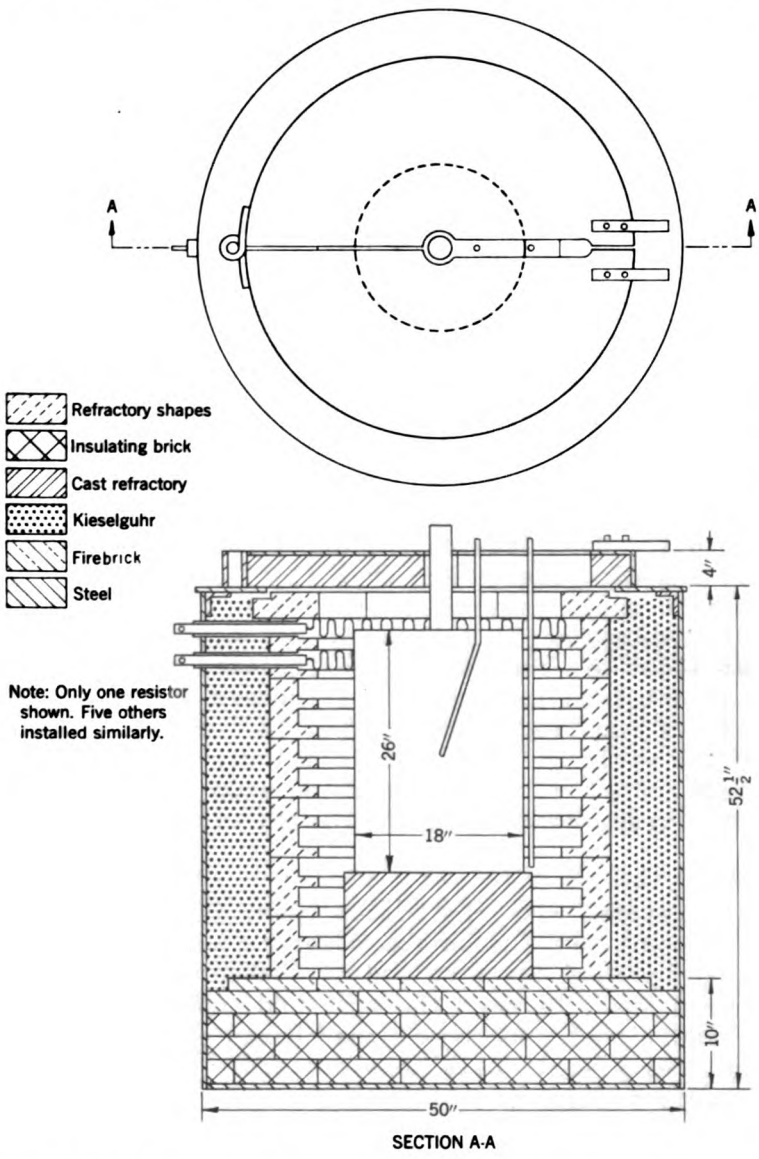

FIGURE 1. - Cross Section of BM-AGA Furnace and Retort.

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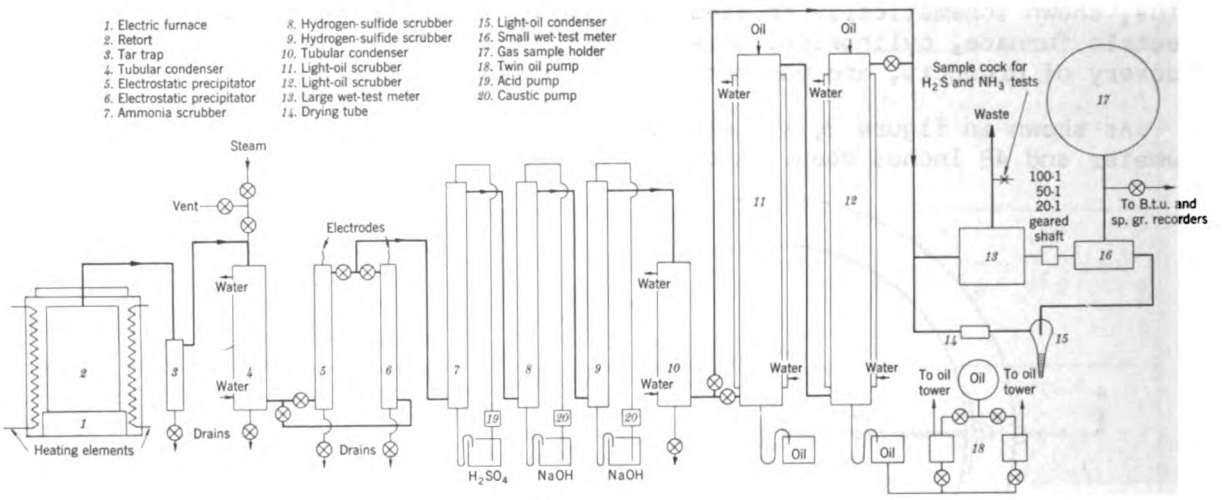

FIGURE 2. - Flow Diagram of BM-AGA Carbonizing Apparatus.

passes through the tubular condenser (10), where it is cooled with refrigerated water to dehydrate partially the gas before entering the wash-oil scrubbers (11 and 12), which are also cooled with refrigerated water. This preliminary cooling prevents condensation in the oil scrubbers, which causes difficulty in subsequent stripping by the wash oil. Upon leaving the oil scrubbers, the gas is metered (13 and 16), sampled, and discarded. Residual light oil in the sampled portion of the gas (about 10 cubic feet) is recovered in the light oil condenser (15), which is partially submerged in a bath of acetone and solid carbon dioxide. The quantity of light oil recovered is calculated to a total gas yield basis and added to that obtained from the oil scrubbers. When distillation of the light oil is not required to determine its composition, the oil scrubbers are bypassed, and the yield of light oil is calculated from that recovered in the condenser. Steam, which is shown connected atop condenser (4), is used to remove tar from the tar trap, condenser, and piping at the conclusion of the test.

In preparing for a test, the retort, with the bottom open, is inverted and filled with a weighed quantity of coal, and the bottom cover is welded in place. After the retort is returned to an upright position and is shaken slightly to level the top of the coal, the void space between the coal and top of the retort is adjusted to 1 inch by either additional packing of the charge or adding coal through the retort off-take pipe. With most coals this procedure gives a bulk density of about 50 pounds per cubic foot.

The carbonizing furnace is preheated to a temperature 50° C. above the desired test temperature to compensate for the heat loss when the retort is charged. After an initial recovery period of about 15 minutes, the retort

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wall is held at a constant temperature (± 5° C.) by automatic control of the power input to the furnace. The control is activated by a single-point chromel-alumel thermocouple located on the retort wall midway between top and bottom. The couple is encased in 1/8-inch black iron pipe welded to the retort wall. Because of the marked influence of temperature on carbonization results, the indication of the control couple is checked manually every 15 minutes with an entirely independent system having a thermocouple permanently mounted in the furnace wall.

Scrubbing solutions are recycled throughout the test, and auxiliary tests are made periodically to determine if removal of ammonia and hydrogen sulfide is complete.

The test is discontinued when the rate of gas evolution, measured at the meter, reaches a predetermined value, which experience has shown is attained when the coke temperature at the center of the retort is within 25° C. of the wall temperature. For tests at 900° C., this value is 1 cubic foot in 3 minutes.

At the conclusion of the test, the retort is removed from the furnace and allowed to cool to room temperature, after which the bottom is cut off with a cold chisel, and the coke is removed and weighed. As the coke is being removed from the retort, about 15 pounds are selected, beginning about 6 inches from the bottom, to determine apparent specific gravity. This coke is later dried and included in the coke used for shatter and tumbler tests.

Shatter and tumbler tests of BM-AGA cokes are conducted in accordance with ASTM specifications. Size analyses of the cokes as discharged from the retort have been discontinued for high-temperature coke because of poor agreement between duplicates.

APPENDIX II

The 50-Pound, 10-Inch Circular Retort

The 50-pound, 10-inch circular gas-fired retort used by the Bureau at Denver, Colo., is a modified BM-AGA carbonization unit. Byproducts are not collected but are burned in a combustion chamber during tests. A cross section of the retort assembly is shown in figure 3.

The retort is of heat-resisting 16-gage, type 310, stainless steel, 10 inches in diameter and 26 inches in length. The retort assembly is suspended in the furnace by a lever system mounted on a scale. This arrangement permits taking continuous weight readings during carbonization. The retort is heated with controlled mixtures of natural gas and air; products of combustion may be circulated to control the temperature. Retort temperature is maintained by manual control.

The temperature history for a given run is obtained by chromel-alumel thermocouples placed midlength on the inner side of the retort shell and at

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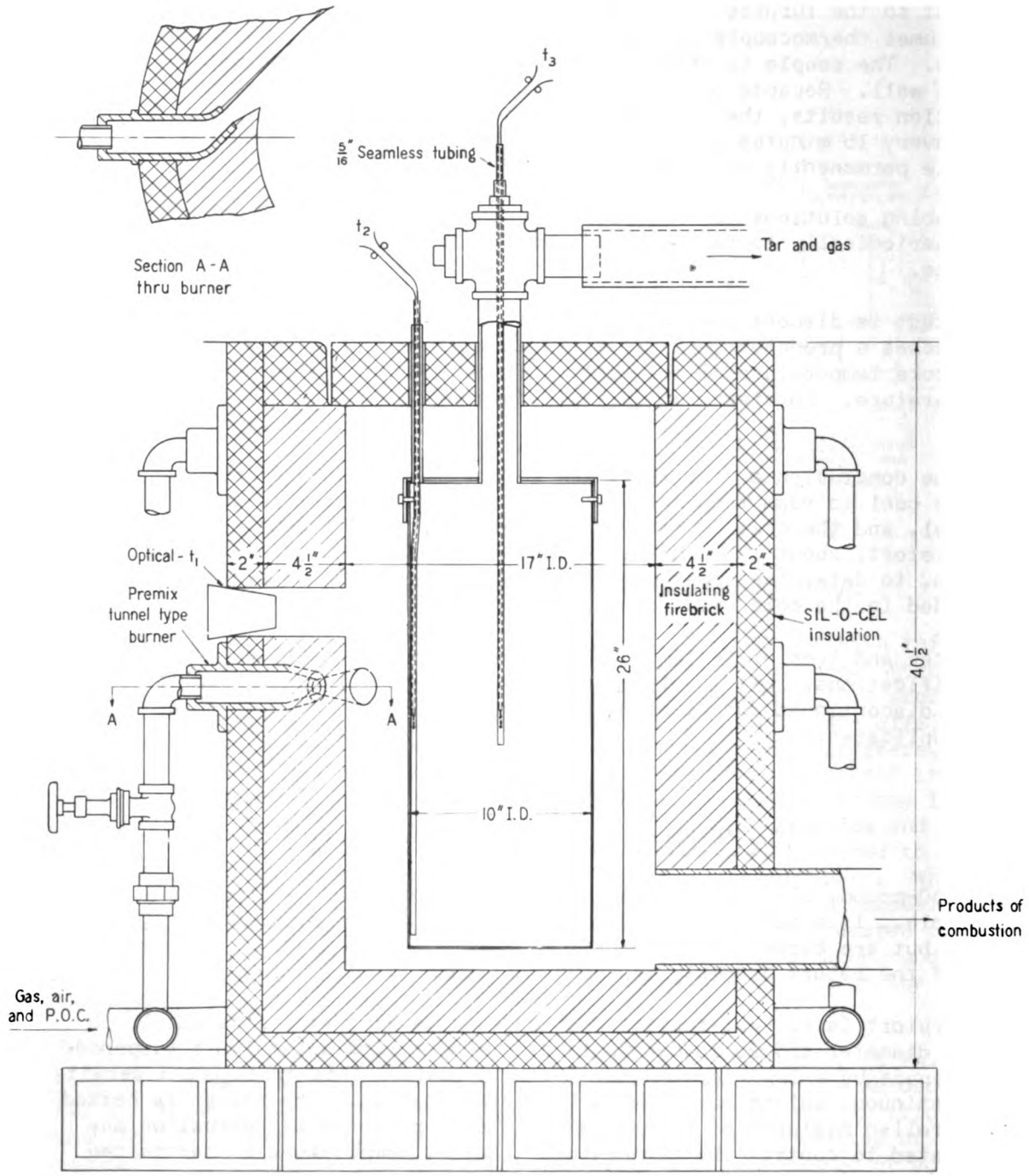

FIGURE 3. - Cross Section of 50-Pound Carbonizing Retort.

the center of the coal charge. At a fixed point on the retort shell, an optical pyrometer measures the outside retort shell temperature.

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Crushed coal (1/4 by 0-inch or smaller) is packed in the retort in layers to a predetermined bulk density. In the tests reported, 1 cubic foot of coal was carbonized. The charged retort is introduced into a preheated furnace. It then is suspended and balanced. After carbonization, the retort is removed from the furnace, is capped, and is allowed to cool to room temperature. The top coke is stripped to the middle of the coke residue, and the coke is photographed in place in the retort. The coke is collected and, in the drop shatter apparatus, is dropped once to stabilize the coke. Physical testing follows, after which a composite sample of the total coke is prepared for chemical analyses.

APPENDIX III

The Denver Coal Research Laboratory 500-Pound Experimental Slot Oven

The 500-pound experimental slot oven is gas-fired with fixed walls. (See figure 4.) This schematic representation shows the supporting steel and the firebrick construction. Oven-wall construction and a detailed section through a flue section is given by figure 5.

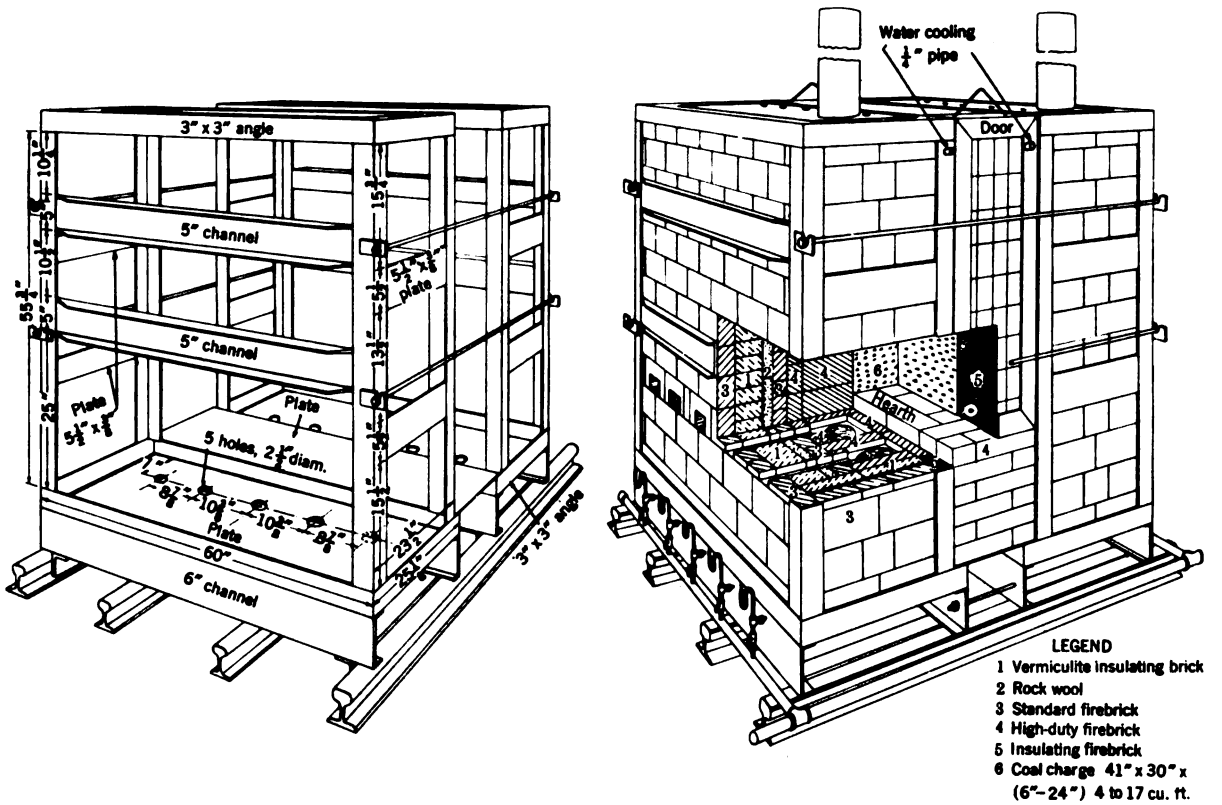

FIGURE 4. - Experimental Coke Oven, 6- to 24-Inch Coking Chamber.

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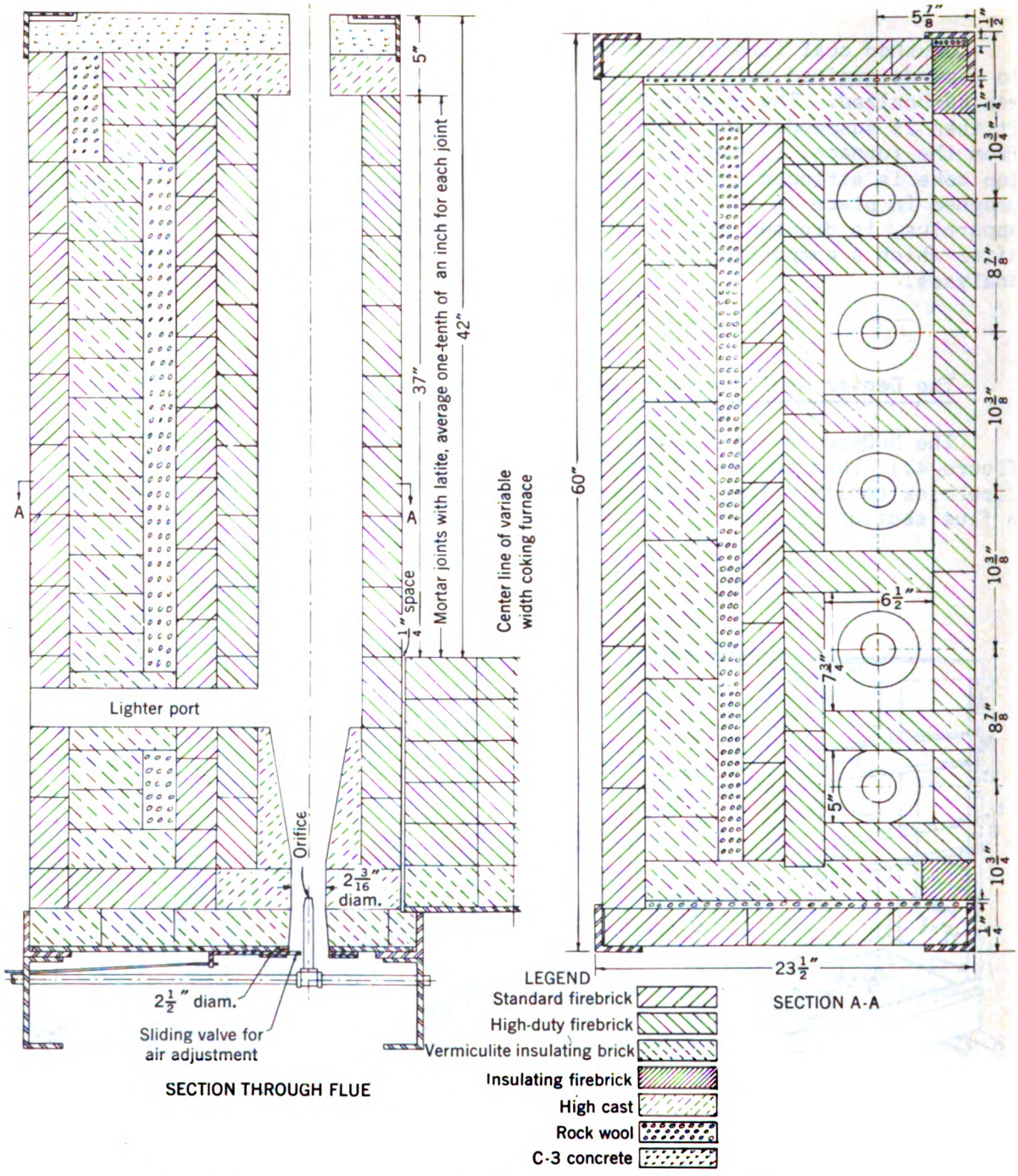

FIGURE 5. - Experimental Coke Oven, Cross Section and Elevation.

The oven chamber is 36 inches high, 40 inches long, and permits an adjustable width from 6 to 24 inches. The walls are fixed in position, and no pressure measurements are made. Since the oven utilizes a prepacked box charge, the oven walls have a slight taper of one-half inch to facilitate charging without binding. Depending upon the oven selected, the coal charging

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box will have the dimensions 40 inches in length, 30 inches in height, and a width ranging from 6 to 24 inches. The coal charge will vary with the oven width and will range from 4 to 17 cubic feet of material. At the 14-inch width, approximately 500 pounds of coal is charged. Carbonization tests listed in this report were made at the 14-inch width.

The oven is gas-fired with five vertical flues in each sidewall. Temperature is controlled by manual adjustment of the individual burners in each flue. Flue temperatures are determined by chromel-alumel thermocouples inserted in type 310 stainless steel wells. The coke temperature is determined by six thermocouples placed in similar stainless steel wells located across the horizontal midplane of the coal charge. The thermocouples are spaced as follows: (1) Center of the coal charge, (2) 1-3/8 inches from the center, (3) 2-3/4 inches from the center, (4) 4-3/4 inches from the center, (5) 6-5/8 inches from the center, and (6) the oven wall.

The coal charge is packed in layers to a predetermined bulk density in a plywood box. After the flues have reached the proper temperature, the charging box is pushed into the oven over a greased slide. When the coal charge is heated from both sides, the coal remains in the oven approximately 17 hours. This includes the time required for carbonization (as indicated by the temperature at the center of the charge) plus the tempering or "soaking" time. In all tests reported, the net coking time is arbitrarily assumed to be the time necessary for the temperature of the center of the charge to reach 90 percent of the absolute temperature of the flues. For the tests reported, the gross coking time is the net coking time plus 1.3 to 3.4 hours of tempering or "soaking" time. Carbonization byproducts are not collected but are burned in a combustion chamber during the test.

When carbonization is completed, the coke is pulled into a cooling box and wet-quenched. Since the amount of water for quenching is not measured, the quenched coke is spread in shallow pans and is dried at 100° C. for 3 to 4 hours to eliminate the water remaining in the coke. All chemical and physical tests are made on the dry coke.

The following tests are made on the resultant coke: Chemical analyses, true and apparent specific gravities, screen analysis, ASTM drop shatter, and ASTM tumbler. Screen analysis of the coke is made after dropping the coke once in the standard drop shatter apparatus to stabilize the coke.

APPENDIX IV

The Tuscaloosa 17-Inch Slot-Type Experimental Coke Oven

Carbonization tests at Tuscaloosa were conducted with the Tuscaloosa oven which has been described previously[7]. It features an electrically (globar)

7/ Gayle, J. B., and Eddy, W. H., Carbonizing Tests with Tuscaloosa Oven 1952-53: Bureau of Mines Rept. of Investigations 5125, 1955, 16 pp.; Proc. Blast Furnace, Coke Oven & Raw Materials Conference, AIME, April 14-16, 1958, Cleveland, Ohio, vol. 17, pp. 193-212; Studies of Coke Oven Width, Flue Temperature and Coking Rate, Bureau of Mines Report of Investigations 5592, 1960, 35 pp.

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heated carbonizing chamber 17 inches wide, 3 feet long and 4 feet high (see fig. 6). The heating walls are constructed of 4-1/2-inch silica brick to simulate, as closely as possible, heat-transfer conditions in commercial slot-type ovens. Charges range in weight from 760 to 950 pounds, depending upon the moisture content, size distribution, and amount of oil used, and are introduced through an opening in the oven top. One wall of the oven is movable and is equipped with recording hydraulic gages to measure any forces exerted by the charge during carbonization. Supplementary information on coal expansion is obtained by a 1/4-inch open-ended pipe inserted just above the center of the charge through a hole in the pusher end door and connected to a recording gas pressure gage.

Flue temperatures are measured and controlled by platinum-platinum rhodium thermocouples encased in double porcelain wells which are in contact with the flue side of the silica brick heating walls. Ten thermocouples are used to control seven circuits having a total of 20 globar heating elements. Progress of carbonization is followed by iron-constantan thermocouples encased in 1/4-inch close-ended iron pipes and inserted into the charge through openings in the pusher end door.

Programming of the heating schedule consists simply of setting the various temperature controllers for the desired flue temperature. No further adjustment is necessary; the rate of heat transfer is governed by the thermal characteristics of the heating walls and of the charge.

For convenience in discussion, the coking period is considered to consist of two parts. The first represents the minimum amount of time in which carbonization can be considered substantially complete; the second part is the time allowed for soaking or tempering the charge and normally amounts to around 25 percent of the total coking period.

The first part of the coking period is referred to as the "true" coking time. Numerically, it is the length of time required for the center of the charge to reach a final coke temperature defined by the following equation:

$$FCT = 840 + 0.4FT$$

where:

FCT = final coke temperature at end of "true" coking time, °F.

FT = Flue temperature, °F.

During the soaking period, relatively little change takes place in the physical properties of the coke; the length of the soaking period is therefore not critical.

After soaking for the desired time, the charge is pushed from the oven into a coke lorry, is quenched by hand with a garden hose, is spread on a concrete slab, and is air-dried for at least 1 day. The coke is given a

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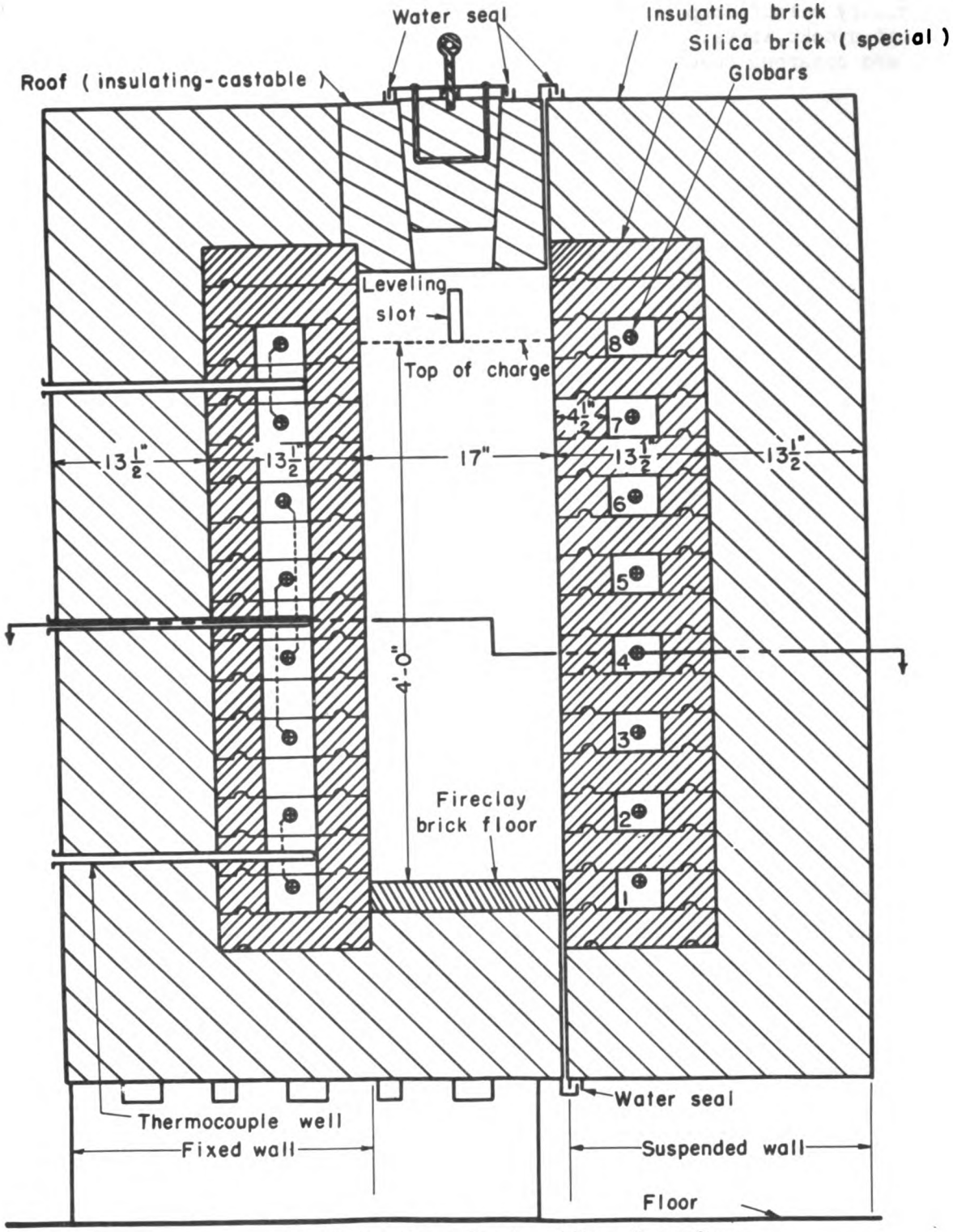

FIGURE 6. - Cross Section of Tuscaloosa Oven.

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preliminary 6-foot drop in the shatter apparatus to simulate handling conditions at a coke works. It is then screened and is subjected to shatter, tumbler, and apparent specific gravity tests in the usual manner.

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